to *t*. Suppoſe now the rays which go to *t* to be the indigo-making rays. It is manifeſt that the boards AB, CD, and priſm NOP remaining immoveable, both the violet-making and indigo-making rays are incident alike upon the priſm NOP, for they are equally inclined to its ſurface OP, and enter it in the ſame part of that ſurface; which ſhews that the indigo-making rays are leſs diverted out of their courſe by the refraction of the priſm, than the violet-making rays under an exact parity of all circumſtances. Farther, if the priſm GHI be more turned about, 'till the blue-making rays paſs through the hole L, theſe ſhall fall upon the ſurface QR below *t*, as at *v*, and therefore are ſubjected to a leſs refraction than the indigo-making rays. And thus by proceeding it will be found that the green-making rays are leſs refracted than the blue-making rays, and ſo of the reſt, according to the order in which they lie in the coloured ſpectrum.

4. THIS diſpoſition of the different coloured rays to be refracted ſome more than others our author calls their reſpective degrees of refrangibility. And ſince this difference of refrangibility diſcovers it ſelf to be ſo regular, the next ſtep is to find the rule it obſerves.

5. IT is a common principle in optics, that the ſine of the angle of incidence bears to the ſine of the refracted angle a given proportion. If AB (in fig. 131, 132) repreſent the ſurface of any refracting ſubſtance, ſuppoſe of water or glaſs, and CD a ray of light incident upon that ſur-

face in the point D, let D E be the ray, after it has paſſed the ſurface A B; if the ray paſs out of the air into the ſubſtance whoſe ſurface is A B (as in fig. 131) it ſhall be turned from the ſurface, and if it paſs out of that ſubſtance into air it ſhall be bent towards it (as in fig. 132) But if F G be drawn through the point D perpendicular to the ſurface A B, the angle under C D F made by the incident ray and this perpendicular is called the angle of incidence; and the angle under E D G, made by this perpendicular and the ray after refraction, is called the refracted angle. And if the circle H F I G be deſcribed with any interval cutting C D in H and D E in I, then the perpendiculars H K, I L being let fall upon F G, H K is called the ſine of the angle under C D F the angle of incidence, and I L the ſine of the angle under E D G the refracted angle. The firſt of theſe ſines is called the ſine of the angle of incidence, or more briefly the ſine of incidence, the latter is the ſine of the refracted angle, or the ſine of refraction. And it has been found by numerous experiments that whatever proportion the ſine of incidence H K bears to the ſine of refraction I L in any one caſe, the ſame proportion ſhall hold in all caſes; that is, the proportion between theſe ſines will remain unalterably the ſame in the ſame refracting ſubſtance, whatever be the magnitude of the angle under C D F.

6. But now becauſe optical writers did not obſerve that every beam of white light was divided by refraction, as has been here explained, this rule collected by them can only be underſtood in the groſs of the whole beam after re-

fraction, and not ſo much of any particular part of it, or at moſt only of the middle part of the beam. It therefore was incumbent upon our author to find by what law the rays were parted from each other; whether each ray apart obtained this property, and that the ſeparation was made by the proportion between the ſines of incidence and refraction being in each ſpecies of rays different; or whether the light was divided by ſome other rule. But he proves by a certain experiment that each ray has its ſine of incidence proportional to its ſine of refraction; and farther ſhews by mathematical reaſoning, that it muſt be ſo upon condition only that bodies refract the light by acting upon it, in a direction perpendicular to the ſurface of the refracting body, and upon the ſame ſort of rays always in an equal degree at the ſame diſtances[a].

7. OUR great author teaches in the next place how from the refraction of the moſt refrangible and leaſt refrangible rays to find the refraction of all the intermediate ones[b]. The method is this: if the ſine of incidence be to the ſine of refraction in the leaſt refrangible rays as A to B C, (in fig. 133) and to the ſine of refraction in the moſt refrangible as A to B D; if C E be taken equal to C D, and then E D be ſo divided in F, G, H, I, K, L, that ED, EF, EG, EH, EI, EK, EL, EC, ſhall be proportional to the eight lengths of muſical chords, which ſound the notes in an octave, E D being the length of the key, E F the length of the tone above

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[a] Opt. pag. 67, 68, &c.

[b] Ibid. B. I, par. 2. prop. 3.

that key, E G the length of the leſſer third, E H of the fourth, E I of the fifth, E K of the greater ſixth, E L of the ſeventh, and E C of the octave above that key; that is if the lines E D, E F, E G, E H, E I, E K, E L, and E C bear the ſame proportion as the numbers, 1, $\frac{9}{8}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{1}{3}$, $\frac{3}{4}$, $\frac{9}{61}$, $\frac{1}{2}$, reſpectively then ſhall B D, BF, be the two limits of the ſines of refraction of the violet-making rays, that is the violet-making rays ſhall not all of them have preciſely the ſame ſine of refraction, but none of them ſhall have a greater ſine than B D, nor a leſs than B F, though there are violet-making rays which anſwer to any ſine of refraction that can be taken between theſe two. In the ſame manner B F and B G are the limits of the ſines of refraction of the indigo-making rays; B G, B H are the limits belonging to the blue-making rays; B H, B I the limits pertaining to the green-making rays, B I, B K the limits for the yellow-making rays; B K, B L the limits for the orange-making rays; and laſtly, B L and B C the extreme limits of the ſines of refraction belonging to the red-making rays. Theſe are the proportions by which the heterogeneous rays of light are ſeparated from each other in refraction.

8. When light paſſes out of glaſs into air, our author found A to B C as 50 to 77, and the ſame A to B D as 50 to 78. And when it goes out of any other refracting ſubſtance into air, the exceſs of the ſine of refraction of any one ſpecies of rays above its ſine of incidence bears a conſtant proportion, which holds the ſame in each ſpecies, to the exceſs of the ſine of refraction of the ſame ſort of rays

above the ſine of incidence into the air out of glaſs; provided the ſines of incidence both in glaſs and the other ſubſtance are equal. This our author verified by tranſmitting the light through priſms of glaſs included within a priſmatic veſſel of water; and draws from thoſe experiments the following obſervations: that whenever the light in paſſing through ſo many ſurfaces parting diverſe tranſparent ſubſtances is by contrary refractions made to emerge into the air in a direction parallel to that of its incidence, it will appear afterwards white at any diſtance from the priſms, where you ſhall pleaſe to examine it; but if the direction of its emergence be oblique to its incidence, in receding from the place of emergence its edges ſhall appear tinged with colours: which proves that in the firſt caſe there is no inequality in the refractions of each ſpecies of rays, but that when any one ſpecies is ſo refracted as to emerge parallel to the incident rays, every ſort of rays after refraction ſhall likewiſe be parallel to the ſame incident rays, and to each other; whereas on the contrary, if the rays of any one ſort are oblique to the incident light, the ſeveral ſpecies ſhall be oblique to each other, and be gradually ſeparated by that obliquity. From hence he deduces both the forementioned theorem, and alſo this other; that in each ſort of rays the proportion of the ſine of incidence to the ſine of refraction, in the paſſage of the ray out of any refracting ſubſtance into another, is compounded of the proportion to which the ſine of incidence would have to the ſine of refraction in the paſſage of that ray out of the firſt ſubſtance into any third, and of the proportion which the ſine of incidence would have to the ſine of refraction in the paſſage of the ray out of that third ſubſtance into the ſecond. From ſo ſimple and plain an experiment has our moſt judicious author deduced theſe important theorems, by which we may learn how very exact and circumſpect he has been in this whole work of his optics; that notwithſtanding his great particularity in explaining his doctrine, and the numerous collection of experiments he has made to clear up every doubt which could ariſe, yet at the ſame time he has uſed the greateſt caution to make out every thing by the ſimpleſt and eaſieſt means poſſible.

9. Our author adds but one remark more upon refraction, which is, that if refraction be performed in the manner he has ſuppoſed from the light's being preſſed by the refracting power perpendicularly toward the ſurface of the refracting body, and conſequently be made to move ſwifter in the body than before its incidence; whether this power act equally at all diſtances or otherwiſe, provided only its power in the ſame body at the ſame diſtances remain without variation the ſame in one inclination of the incident rays as well as another; he obſerves that the refracting powers in different bodies will be in the duplicate proportion of the tangents of the leaſt angles, which the refracted light can make with the ſurfaces of the refracting bodies [a]. This obſervation may be explained thus. When the light paſſes into any refracting ſubſtance, it has been ſhewn above that the ſine of incidence bears a conſtant proportion to the ſine

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[a] Opt. B. II. par. 3. prop. 10.

of refraction. Suppoſe the light to paſs to the refracting body ABCD (in fig. 134) in the line EF, and to fall upon it at the point F, and then to proceed within the body in the line FG. Let HI be drawn through F perpendicular to the ſurface AB, and any circle KLMN be deſcribed to the center F. Then from the points O and P where this circle cuts the incident and refracted ray, the perpendiculars OQ, PR being drawn, the proportion of OQ to PR will remain the ſame in all the different obliquities, in which the ſame ray of light can fall on the ſurface AB. Now OQ is leſs than FL the ſemidiameter of the circle KLMN, but the more the ray EF is inclined down toward the ſurface AB, the greater will OQ be, and will approach nearer to the magnitude of FL. But the proportion of OQ to PR remaining always the ſame, when OQ is largeſt, PR will alſo be greateſt; ſo that the more the incident ray EF is inclined toward the ſurface AB, the more the ray FG after refraction will be inclined toward the ſame. Now if the line FST be ſo drawn, that SV being perpendicular to FI ſhall be to FL the ſemidiameter of the circle in the conſtant proportion of PR to OQ; then the angle under NFT is that which I meant by the leaſt of all that can be made by the refracted ray with this ſurface, for the ray after refraction would proceed in this line, if it were to come to the point F lying on the very ſurface AB; for if the incident ray came to the point F in any line between AF and FH, the ray after refraction would proceed forward in ſome line between FT and FI. Here if NW be drawn perpendicular to FN, this line NW in the circle KLMN is called the tangent of the angle under NFS. Thus much being premiſed, the ſenſe of the forementioned propoſition is this. Let there be two refracting ſubſtances (in fig. 135) ABCD, and EFGH. Take a point, as I, in the ſurface AB, and to the center I with any ſemidiameter deſcribe the circle KLM. In like manner on the ſurface EF take ſome point N, as a center, and deſcribe with the ſame ſemidiameter the circle OPQ. Let the angle under BIR be the leaſt which the refracted light can make with the ſurface AB, and the angle under FNS the leaſt which the refracted light can make with the ſurface EF. Then if LT be drawn perpendicular to AB, and PV perpendicular to EF; the whole power, wherewith the ſubſtance ABCD acts on the light, will bear to the whole power wherewith the ſubſtance EFGH acts on, the light, a proportion, which is duplicate of the proportion, which LT bears to PV.

10. UPON comparing according to this rule the refractive powers of a great many bodies it is found, that unctuous bodies which abound moſt with ſulphureous parts refract the light two or three times more in proportion to their denſity than others: but that thoſe bodies, which ſeem to receive in their compoſition like proportions of ſulphureous parts, have their refractive powers proportional to their denſities; as appears beyond contradiction by comparing the refractive power of ſo rare a ſubſtance as the air with that of common glaſs or rock cryſtal, though theſe ſubſtances are 2000 times denſer than air; nay the ſame pro-

portion is found to hold without ſenſible difference in comparing air with pſeudo-~~topar~~ and glaſs of antimony, though the pſeudo-topar be 3500 times denſer than air, and glaſs of antimony no leſs than 4400 times denſer. This power in other ſubſtances, as ſalts, common water, ſpirit of wine, &c. ſeems to bear a greater proportion to their denſities than theſe laſt named, according as they abound with ſulphurs more than theſe; which makes our author conclude it probable, that bodies act upon the light chiefly, if not altogether, by means of the ſulphurs in them; which kind of ſubſtances it is likely enters in ſome degree the compoſition of all bodies. Of all the ſubſtances examined by our author, none has ſo great a refractive power, in reſpect of its denſity, as a diamond.

11. OUR author finiſhes theſe remarks, and all he offers relating to refraction, with obſerving, that the action between light and bodies is mutual, ſince ſulphureous bodies, which are moſt readily ſet on fire by the ſun's light, when collected upon them with a burning glaſs, act more upon light in refracting it, than other bodies of the ſame denſity do. And farther, that the denſeſt bodies, which have been now ſhewn to act moſt upon light, contract the greateſt heat by being expoſed to the ſummer ſun.

12. HAVING thus diſpatched what relates to refraction, we muſt addreſs ourſelves to diſcourſe of the other operation of bodies upon light in reflecting it. When light paſſes through a ſurface, which divides two tranſparent bodies

dies differing in denſity, part of it only is tranſmitted, another part being reflected. And if the light paſs out of the denſer body into the rarer, by being much inclined to the foreſaid ſurface at length no part of it ſhall paſs through, but be totally reflected. Now that part of the light, which ſuffers the greateſt refraction, ſhall be wholly reflected with a leſs obliquity of the rays, than the parts of the light which undergo a leſs degree of refraction; as is evident from the laſt experiment recited in the firſt chapter; where, as the priſms DEF, GHI, (in fig. 129.) were turned about, the violet light was firſt totally reflected, and then the blue, next tothat the green, and ſo of the reſt. In conſequence of which our author lays down this propoſition; that the ſun's light differs in reflexibility, thoſe rays being moſt reflexible, which are moſt refrangible. And collects from this, in conjunction with other arguments, that the refraction and reflection of light are produced by the ſame cauſe, compaſſing thoſe different effects only by the difference of circumſtances with which it is attended. Another proof of this being taken by our author from what he has diſcovered of the paſſage of light through thin tranſparent plates, viz. that any particular ſpecies of light, ſuppoſe, for inſtance, the red-making rays, will enter and paſs out of ſuch a plate, if that plate be of ſome certain thickneſſes; but if it be of other thickneſſes, it will not break through it, but be reflected back: in which is ſeen, that the thickneſs of the plate determines whether the power, by which that plate acts upon the light, ſhall reflect it, or ſuffer it to paſs through.

13. But this laſt mentioned ſurpriſing property of the action between light and bodies affords the reaſon of all that has been ſaid in the preceding chapter concerning the colours of natural bodies; and muſt therefore more particularly be illuſtrated and explained, as being what will principally unfold the nature of the action of bodies upon light.

14. To begin: The object glaſs of a long teleſcope being laid upon a plane glaſs, as propoſed in the foregoing chapter, in open day-light there will be exhibited rings of various colours, as was there related; but if in a darkened room the coloured ſpectrum be formed by the priſm, as in the firſt experiment of the firſt chapter, and the glaſſes be illuminated by a reflection from the ſpectrum, the rings ſhall not in this caſe exhibit the diverſity of colours before deſcribed, but appear all of the colour of the light which falls upon the glaſſes, having dark rings between. Which ſhews that the thin plate of air between the glaſſes at ſome thickneſſes reflects the incident light, at other places does not reflect it, but is found in thoſe places to give the light paſſage; for by holding the glaſſes in the light as it paſſes from the priſm to the ſpectrum, ſuppoſe at ſuch a diſtance from the priſm that the ſeveral ſorts of light muſt be ſufficiently ſeparated from each other, when any particular ſort of light falls on the glaſſes, you will find by holding a piece of white paper at a ſmall diſtance beyond the glaſſes, that at thoſe intervals, where the dark rings appeared upon the glaſſes, the light is ſo tranſmitted,

as to paint upon the paper rings of light having that colour which falls upon the glaſſes. This experiment therefore opens to us this very ſtrange property of reflection, that in theſe thin plates it ſhould bear ſuch a relation to the thickneſs of the plate, as is here ſhewn. Farther, by carefully meaſuring the diameters of each ring it is found, that whereas the glaſſes touch where the dark ſpot appears in the center of the rings made by reflection, where the air is of twice the thickneſs at which the light of the firſt ring is reflected, there the light by being again tranſmitted makes the firſt dark ring; where the plate has three times that thickneſs which exhibits the firſt lucid ring, it again reflects the light forming the ſecond lucid ring; when the thickneſs is four times the firſt, the light is again tranſmitted ſo as to make the ſecond dark ring; where the air is five times the firſt thickneſs, the third lucid ring is made; where it has ſix times the thickneſs, the third dark ring appears, and ſo on: in ſo much that the thickneſſes, at which the light is reflected, are in proportion to the numbers 1, 3, 5, 7, 9, &c. and the thickneſſes, where the light is tranſmitted, are in the proportion of the numbers 0, 2, 4, 6, 8, &c. And theſe proportions between the thickneſſes which reflect and tranſmit the light remain the ſame in all ſituations of the eye, as well when the rings are viewed obliquely, as when looked on perpendicularly. We muſt farther here obſerve, that the light, when it is reflected, as well as when it is tranſmitted, enters the thin plate, and is reflected from its farther ſurface; becauſe, as was before remarked, the altering the tranſparent body behind the farther ſurface alters the degree of reflection as when a thin piece of Muſcovy glaſs has its farther ſurface wet with water, and the colour of the glaſs made dimmer by being ſo wet; which ſhews that the light reaches to the water, otherwiſe its reflection could not be influenced by it. But yet this reflection depends upon ſome power propagated from the firſt ſurface to the ſecond; for though made at the ſecond ſurface it depends alſo upon the firſt, becauſe it depends upon the diſtance between the ſurfaces; and beſides, the body through which the light paſſes to the firſt ſurface influences the reflection: for in a plate of Muſcovy glaſs, wetting the ſurface, which firſt receives the light, diminiſhes the reflection, though not quite ſo much as wetting the farther ſurface will do. Since therefore the light in paſſing through theſe thin plates at ſome thickneſſes is reflected, but at others tranſmitted without reflection, it is evident, that this reflection is cauſed by ſome power propagated from the firſt ſurface, which intermits and returns ſucceſſively. Thus is every ray apart diſpoſed to alternate reflections and tranſmiſſions at equal intervals; the ſucceſſive returns of which diſpoſition our author calls the fits of eaſy reflection, and of eaſy tranſmiſſion. But theſe fits, which obſerve the ſame law of returning at equal intervals, whether the plates are viewed perpendicularly or obliquely, in different ſituations of the eye change their magnitude. For what was obſerved before in reſpect of thoſe rings, which appear in open day-light, holds likewiſe in theſe rings exhibited by ſimple lights; namely, that theſe two alter in bigneſs according to the different angle under which they are ſeen: and our author

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lays down a rule whereby to determine the thickneſſes of the plate of air, which ſhall exhibit the ſame colour under different oblique views[a]. And the thickneſs of the aereal plate, which in different inclinations of the rays will exhibit to the eye in open day-light the ſame colour, is alſo varied by the ſame rule[b]. He contrived farther a method of comparing in the bubble of water the proportion between the thickneſs of its coat, which exhibited any colour when ſeen perpendicularly, to the thickneſs of it, where the ſame colour appeared by an oblique view; and he found the ſame rule to obtain here likewiſe[c]. But farther, if the glaſſes be enlightened ſucceſſively by all the ſeveral ſpecies of light, the rings will appear of different magnitudes; in the red light they will be larger than in the orange colour, in that larger than in the yellow, in the yellow larger than in the green, leſs in the blue, leſs yet in the indigo, and leaſt of all in the violet: which ſhews that the ſame thickneſs of the aereal plate is not fitted to reflect all colours, but that one colour is reflected where another would have been tranſmitted; and as the rays which are moſt ſtrongly refracted form the leaſt rings, a rule is laid down by our author for determining the relation, which the degree of refraction of each ſpecies of colour has to the thickneſſes of the plate where it is reflected.

15. FROM theſe obſervations our author ſhews the reaſon of that great variety of colours, which appears in theſe thin plates in the open white light of the day. For when this white

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[a] Opt. B. II. par. 3. prop. 15.

[b] Ibid. par. 1. obſerv. 7.

[c] Ibid. Obſerv. 19.

light falls on the plate, each part of the light forms rings of its own colour; and the rings of the different colours not being of the ſame bigneſs are variouſly intermixed, and form a great variety of tints[a]

16. IN certain experiments, which our author made with thick glaſſes, he found, that theſe fits of eaſy reflection and tranſmiſſion returned for ſome thouſands of times, and thereby farther confirmed his reaſoning concerning them[b].

17. UPON the whole, our great author concludes from ſome of the experiments made by him, that the reaſon why all tranſparent bodies refract part of the light incident upon them, and reflect another part, is, becauſe ſome of the light, when it comes to the ſurface of the body, is in a fit of eaſy tranſmiſſion, and ſome part of it in a fit of eaſy reflection; and from the durableneſs of theſe fits he thinks it probable, that the light is put into theſe fits from their firſt emiſſion out of the luminous body; and that theſe fits continue to return at equal intervals without end, unleſs thoſe intervals be changed by the light's entring into ſome refracting ſubſtance[c]. He likewiſe has taught how to determine the change which is made of the intervals of the fits of eaſy tranſmiſſion and reflection, when the light paſſes out of one tranſparent ſpace or ſubſtance into another. His rule is, that when the light paſſes perpendicularly to the ſurface, which parts any two tranſparent ſubſtances, theſe intervals in the ſubſtance, out of

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[a] Opt. B. II. par. 2. pag. 199. &c.

[b] Ibid. par. 4.

[c] Ibid. part. 3. prop. 17.

which the light paſſes, bear to the intervals in the ſubſtance, whereinto the light enters, the ſame proportion, as the ſine of incidence bears to the ſine of refraction [a]. It is farther to be obſerved, that though the fits of eaſy reflection return at conſtant intervals, yet the reflecting power never operates, but at or near a ſurface where the light would ſuffer refraction; and if the thickneſs of any tranſparent body ſhall be leſs than the intervals of the fits, thoſe intervals ſhall ſcarce be diſturbed by ſuch a body, but the light ſhall paſs through without any reflection [b]

18. What the power in nature is, whereby this action between light and bodies is cauſed, our author has not diſcovered. But the effects, which he has diſcovered, of this power are very ſurpriſing, and altogether wide from any conjectures that had ever been framed concerning it; and from theſe diſcoveries of his no doubt this power is to be deduced, if we ever can come to the knowledge of it. Sir Isaac Newton has in general hinted at his opinion concerning it; that probably it is owing to ſome very ſubtle and elaſtic ſubſtance diffuſed through the univerſe, in which ſuch vibrations may be excited by the rays of light, as they paſs through it, that ſhall occaſion it to operate ſo differently upon the light in different places as to give riſe to theſe alternate fits of reflection and tranſmiſſion, of which we have now been ſpeaking [c]. He is of opinion, that ſuch a ſubſtance may produce this, and other effects alſo in nature, though it be ſo rare as not to give any ſenſible reſiſtance to bodies in mo-

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[a] Ibid. prop. 17.

[b] Ibid prop, 13.

[c] Opt. Qu. 18, &c.

tion[a]; and therefore not inconſiſtent with what has been ſaid above, that the planets move in ſpaces free from reſiſtance[b].

19. IN order for the more full diſcovery of this action between light and bodies, our author began another ſet of experiments, wherein he found the light to be acted on as it paſſes near the edges of ſolid bodies; in particular all ſmall bodies, ſuch as the hairs of a man's head or the like, held in a very ſmall beam of the ſun's light, caſt extremely broad ſhadows. And in one of theſe experiments the ſhadow was 35 times the breadth of the body[c]. Theſe ſhadows are alſo obſerved to be bordered with colours[d]. This our author calls the inflection of light; but as he informs us, that he was interrupted from proſecuting theſe experiments to any length, I need not detain my readers with a more particular account of them.

CHAP. IV.

Of OPTIC GLASSES.

SIR ISAAC NEWTON having deduced from his doctrine of light and colours a ſurpriſing improvement of teleſcopes, of which I intend here to give an account, I ſhall firſt premiſe ſomething in general concerning thoſe inſtruments.

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[a] See Concl. S. 2.

[b] B. II. Ch. 1.

[c] Opt. B. III. Obſ. 1.

[d] Ibid. Obſ. 2.

2. It will be underſtood from what has been ſaid above, that when light falls upon the ſurface of glaſs obliquely, after its entrance into the glaſs it is more inclined to the line drawn through the point of incidence perpendicular to that ſurface, than before. Suppoſe a ray of light iſſuing from the point A (in fig. 136), falls on a piece of glaſs BCDE, whoſe ſurface BC, whereon the ray falls, is of a ſpherical or globular figure, the center whereof is F. Let the ray proceed in the line AG falling on the ſurface BC in the point G, and draw FGH. Here the ray after its entrance into the glaſs will paſs on in ſome line, as GI, more inclined toward the line FGH that the line AG is inclined thereto; for the line FGH is perpendicular to the ſurface BC in the point G. By this means, if a number of rays proceeding from any one point fall on a convex ſpherical ſurface of glaſs, they ſhall be inflected (as is repreſented in fig. 137,) ſo as to be gathered pretty cloſe together about the line drawn through the center of the glaſs from the point, whence the rays proceed; which line henceforward we ſhall call the axis of the glaſs: or the point from whence the rays proceed may be ſo near the glaſs, that the rays ſhall after entring the glaſs ſtill go on to ſpread themſelves, but not ſo much as before; ſo that if the rays were to be continued backward (as in fig. 138,) they ſhould gather together about the axis at a place more remote from the glaſs, than the point is, whence they actually proceed. In theſe and the following figures A denotes the point to which the rays are related before refraction, B the point to which they are directed afterwards, and C the center of the refracting ſurface. Here we may obſerve, that it is poſſible to form the glaſs of ſuch a figure, that all the rays which proceed from one point

ſhall after refraction be reduced again exactly into one point on the axis of the glaſs. But in glaſſes of a ſpherical form though this does not happen; yet the rays, which fall within a moderate diſtance from the axis, will unite extremely near together. If the light fall on a concave ſpherical ſurface, after refraction it ſhall ſpread quicker than before (as in fig. 139,) unleſs the rays proceed from a point between the center and the ſurface of the glaſs. If we ſuppoſe the rays of light, which fall upon the glaſs, not to proceed from any point, but to move ſo as to tend all to ſome point in the axis of the glaſs beyond the ſurface; if the glaſs have a convex ſurface, the rays ſhall unite about the axis ſooner, than otherwiſe they would do (as in fig. 140,) unleſs the point to which they tended was between the ſurface and the center of that ſurface. But if the ſurface be concave, they ſhall not meet ſo ſoon: nay perhaps ~~converge~~. (See fig. 141 and 142.)

3. FARTHER, becauſe the light in paſſing out of glaſs into the air is turned by the refraction farther off from the line drawn through the point of incidence perpendicular to the refracting ſurface, than it was before; the light which ſpreads from a point ſhall by paſſing through a convex ſurface of glaſs into the air be made either to ſpread leſs than before (as in fig. 143,) or to gather about the axis beyond the glaſs (as in fig. 144.) But if the rays of light were proceeding to a point in the axis of the glaſs, they ſhould by the refraction be made to unite ſooner about that axis (as in fig. 145.) If the ſurface of the glaſs be concave, rays which proceed from a point ſhall be made to ſpread faſter (as in fig. 146,) but rays which are tending to a point in the axis of

the glaſs, ſhall be made to gather about the axis farther from the glaſs (as in fig. 147) or even to diverge (as in fig. 148,) unleſs the point, to which the rays are directed, lies between the ſurface of the glaſs and its center.

4. The rays, which ſpread themſelves from a point, are called diverging; and ſuch as move toward a point, are called converging rays. And the point in the axis of the glaſs, about which the rays gather after refraction, is called the focus of thoſe rays.

5. If a glaſs be formed of two convex ſpherical ſurfaces (as in fig. 149,) where the glaſs AB is formed of the ſurfaces ACB and ADB, the line drawn through the centers of the two ſurfaces, as the line EF, is called the axis of the glaſs; and rays, which diverge from any point of this axis, by the refraction of the glaſs will be cauſed to converge toward ſome part of the axis, or at leaſt to diverge as from a point more remote from the glaſs, than that from whence they proceeded; for the two ſurfaces both conſpire to produce this effect upon the rays. But converging rays will be cauſed by ſuch a glaſs as this to converge ſooner. If a glaſs be formed of two concave ſurfaces, as the glaſs AB (in fig. 150,) the line CD drawn through the centers, to which the two ſurfaces are formed, is called the axis of the glaſs. Such a glaſs ſhall cauſe diverging rays, which proceed from any point in the axis of the glaſs, to diverge much more, as if they came from ſome place in the axis of the glaſs nearer to it than the point,

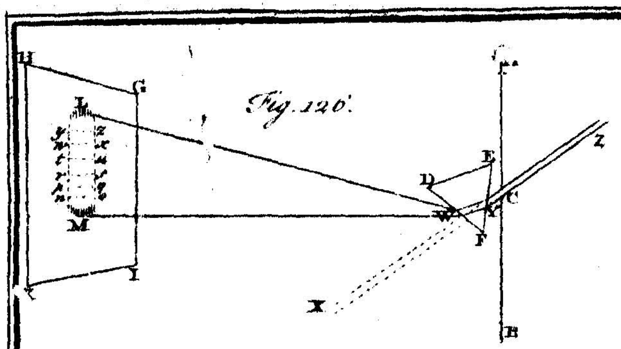

Fig. 126.

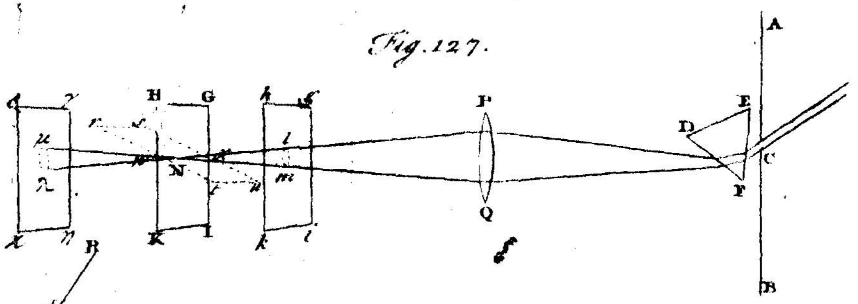

Fig. 127.

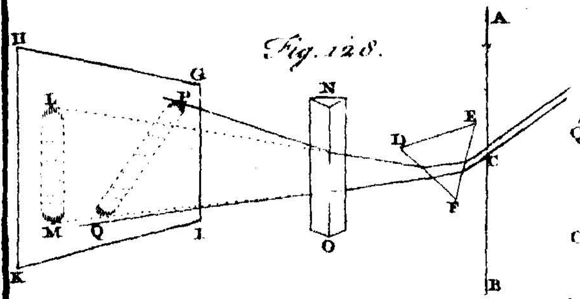

Fig. 128.

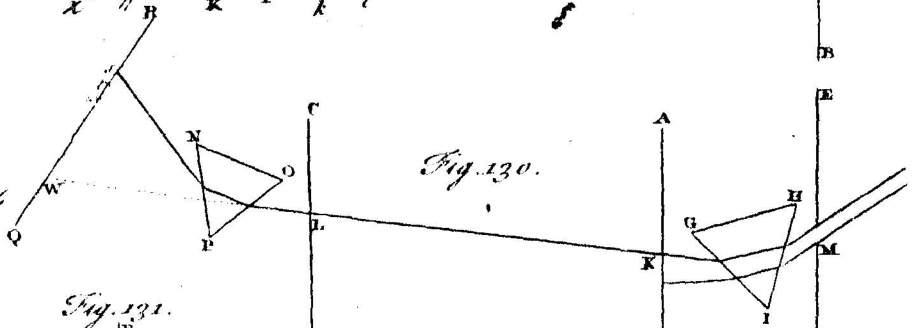

Fig. 130.

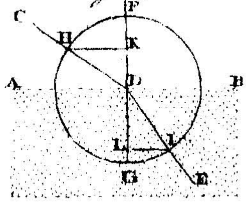

Fig. 131.

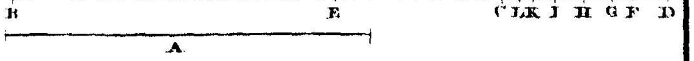

Fig. 133.

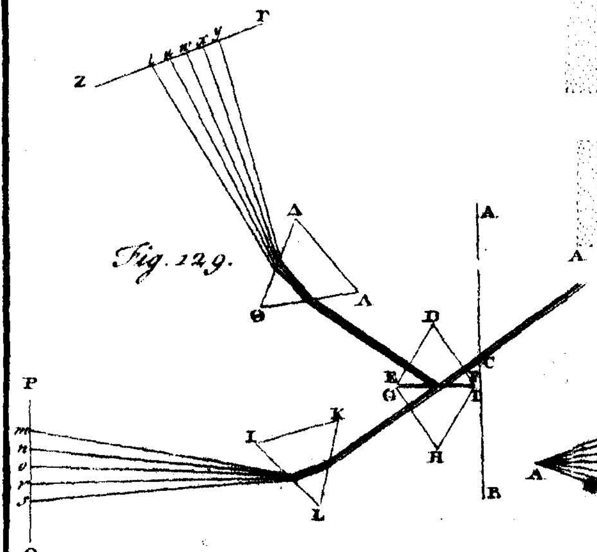

Fig. 129.

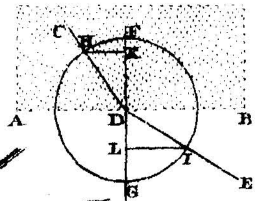

Fig. 132.

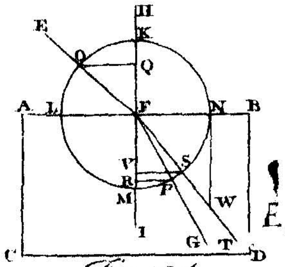

Fig. 134.

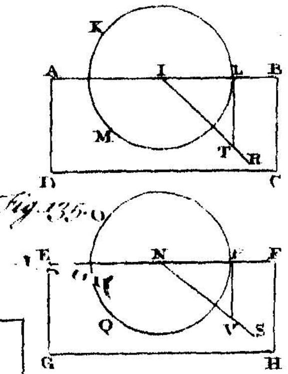

Fig. 135.

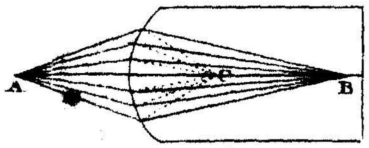

Fig. 137.

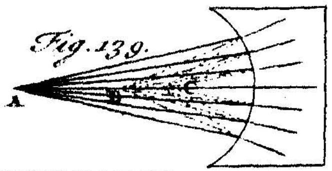

Fig. 139.

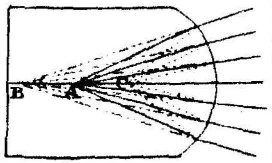

Fig. 143

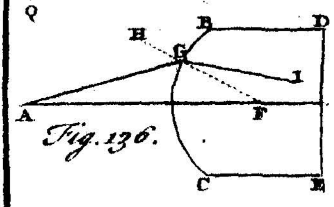

Fig. 136.

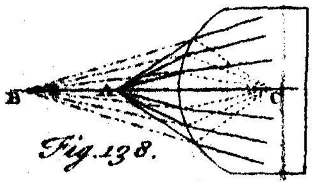

Fig. 138.

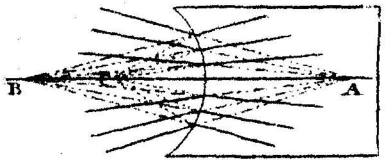

Fig. 142.

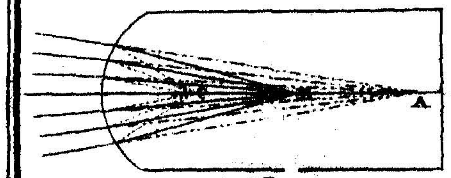

Fig. 140.

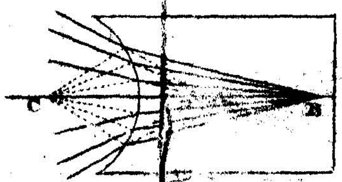

Fig. 141.

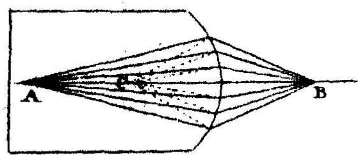

Fig. 144.

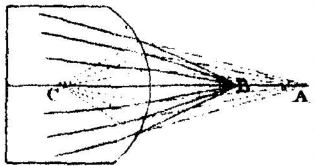

Fig. 145.

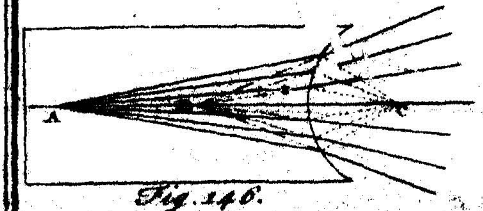

Fig. 146.

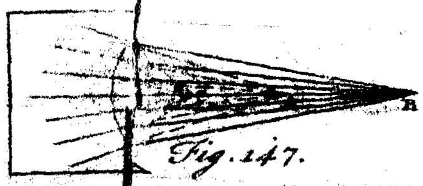

Fig. 147.

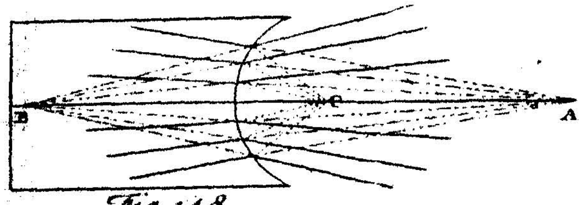

Fig. 148.

whence the rays actually proceed. But converging rays will be made either to converge leſs, or even to diverge.

6. IN theſe glaſſes rays, which proceed from any point near the axis, will be affected as it were in the ſame manner, as if they proceeded from the very axis it ſelf, and ſuch as converge toward a point at a ſmall diſtance from the axis will ſuffer much the ſame effects from the glaſs, as if they converged to ſome point in the very axis. By this means any luminous body expoſed to a convex glaſs may have an image formed upon any white body held beyond the glaſs. This may be eaſily tried with a common ſpectacle-glaſs. For if ſuch a glaſs be held between a candle and a piece of white paper, if the diſtances of the candle, glaſs, and paper be properly adjuſted, the image of the candle will appear very diſtinctly upon the paper, but be ſeen inverted; the reaſon whereof is this. Let AB (in fig. 151) be the glaſs, CD an object placed croſs the axis of the glaſs. Let the rays of light, which iſſue from the point E, where the axis of the glaſs croſſes the object, be ſo refracted by the glaſs, as to meet again about the point F. The rays, which diverge from the point C of the object, ſhall meet again almoſt at the ſame diſtance from the glaſs, but on the other ſide of the axis, as at G; for the rays at the glaſs croſs the axis. In like manner the rays, which proceed from the point D, will meet about H on the other ſide of the axis. None of theſe rays, neither thoſe which proceed from the point E in the axis, nor thoſe which iſſue from C or D, will meet again exactly in one point; but yet in one place, as is here ſuppoſed at F, G, and H, they

will be crouded ſo cloſe together, as to make a diſtinct image of the object upon any body proper to reflect it, which ſhall be held there.

7. IF the object be too near the glaſs for the rays to converge after the refraction, the rays ſhall iſſue out of the glaſs, as if they diverged from a point more diſtant from the glaſs, than that from whence they really proceed (as in fig. 152,) where the rays coming from the point E of the object, which lies on the axis of the glaſs A B, iſſue out of the glaſs, as if they came from the point F more remote from the glaſs than E; and the rays proceeding from the point C iſſue out of the glaſs, as if they proceeded from the point G; likewiſe the rays which iſſue from the point D emerge out of the glaſs, as if they came from the point H. Here the point G is on the ſame ſide of the axis, as the point C; and the point H on the ſame ſide, as the point D. In this caſe to an eye placed beyond the glaſs the object ſhould appear, as if it were in the ſituation G F H.

8. IF the glaſs A B had been concave (as in, fig. 153,) to an eye beyond the glaſs the object C D would appear in the ſituation G H, nearer to the glaſs than really it is. Here alſo the object will not be inverted; but the point G is on the ſame ſide the axe with the point C, and H on the ſame ſide as D.

9. HENCE may be underſtood, why ſpectacles made with convex glaſſes help the ſight in old age: for the eye in that age becomes unfit to ſee objects diſtinctly, except ſuch as are remov'd to a very great diſtance; whence all men, when they firſt ſtand in need of ſpectacles, are obſerved to read at arm's length, and to hold the object at a greater diſtance, than they uſed to do before. But when an object is removed at too great a diſtance from the ſight, it cannot be ſeen clearly, by reaſon that a leſs quantity of light from the object will enter the eye, and the whole object will alſo appear ſmaller. Now by help of a convex glaſs an object may be held near, and yet the rays of light iſſuing from it will enter the eye, as if the object were farther removed.

10. AFTER the ſame manner concave glaſſes aſſiſt ſuch, as are ſhort ſighted. For theſe require the object to be brought inconveniently near to the eye, in order to their ſeeing it diſtinctly; but by ſuch a glaſs the object may be removed to a proper diſtance, and yet the rays of light enter the eye, as if they came from a place much nearer.

11. WHENCE theſe defects of the ſight ariſe, that in old age objects cannot be ſeen diſtinct within a moderate diſtance, and in ſhort-ſightedneſs not without being brought too near, will be eaſily underſtood, when the manner of viſion in general ſhall be explain'd; which I ſhall now endeavour to do, in order to be better underſtood in what

follows. The eye is form'd, as is repreſented in fig. 154. It is of a globular figure, the fore part whereof ſcarce more protuberant than the reſt is tranſparent. Underneath this tranſparent part is a ſmall collection of an humour in appearance like water, and it has alſo the ſame refractive power as common water; this is called the aqueous humour, and fills the ſpace A B C D in the figure. Next beyond lies the body D E F G; this is ſolid but tranſparent, it is compoſed with two convex ſurfaces, the hinder ſurface E F G being more convex, than the anterior E D G. Between the outer membrane A B C, and this body E D G F is placed that membrane, which exhibits the colours, that are ſeen round the ſight of the eye; and the black ſpot, which is called the ſight or pupil, is a hole in this membrane, through which the light enters, whereby we ſee. This membrane is fixed only by its outward circuit, and has a muſcular power, whereby it dilates the pupil in a weak light, and contracts it in a ſtrong one. The body D E F G is called the cryſtalline humour, and has a greater refracting power than water. Behind this the bulk of the eye is filled up with what is called the vitreous humor, this has much the ſame refractive power with water. At the bottom of the eye toward the inner ſide next the noſe the optic glaſs enters, as at H, and ſpreads it ſelf all over the inſide of the eye, till within a ſmall diſtance from A and C. Now any object, as I K, being placed before the eye, the rays of light iſſuing from each point of this object are ſo refracted by the convex ſurface of the aqueous humour, as to be cauſed to converge; after this being received by the convex ſurface E D G of the cryſtalline humour, which has a greater refractive power than the aqueous, the rays, when they are entered into this ſurface, ſtill more converge, and at going out of the ſurface E F G into a humour of a leſs refractive power than the cryſtalline they are made to converge yet farther. By all theſe ſucceſſive refractions they are brought to converge at the bottom of the eye, ſo that a diſtinct image of the ob~~ject as L~~ M is impreſs'd on the nerve. And by this means the object is ſeen.

11. It has been made a difficulty, that the image of the object impreſſed on the nerve is inverted, ſo that the upper part of the image is impreſſed on the lower part of the eye. But this difficulty, I think, can no longer remain, if we only conſider, that upper and lower are terms merely relative to the ordinary poſition of our bodies: and our bodies, when view'd by the eye, have their image as much inverted as other objects; ſo that the image of our own bodies, and of other objects, are impreſſed on the eye in the ſame relation to one another, as they really have.

12. The eye can ſee objects equally diſtinct at very different diſtances, but in one diſtance only at the ſame time. That the eye may accomodate itſelf to different diſtances, ſome change in its humours is requir'd. It is my opinion, that this change is made in the figure of the cryſtalline humour, as I have indeavoured to prove in another place.

3

13. If any of the humours of the eye are too flat, they will refract the light too little; which is the caſe in old age. If they are too convex, they refract too much; as in thoſe who are ſhort-ſighted.

14. The manner of direct viſion being thus explained, I proceed to give ſome account of teleſcopes, by which we view more diſtinctly remote objects; and alſo of microſcopes, whereby we magnify the appearance of ſmall objects. In the firſt place, the moſt ſimple ſort of teleſcope is compoſed of two glaſſes, either both convex, or one convex, and the other concave. (The firſt ſort of theſe is repreſented in fig. 155, the latter in fig. 156.)

15. In fig. 155 let A B repreſent the convex glaſs next the object, C D the other glaſs more convex near the eye. Suppoſe the object-glaſs A B to form the image of the object at E F; ſo that if a ſheet of white paper were to be held in this place, the object would appear. Now ſuppoſe the rays, which paſs the glaſs A B, and are united about F, to proceed to the eye glaſs C D, and be there refracted. Three only of theſe rays are drawn in the figure, thoſe which paſs by the extremities of the glaſs A B, and that which paſſes its middle. If the glaſs C D be placed at ſuch a diſtance from the image E F, that the rays, which paſs by the point F, after having proceeded through the glaſs diverge ſo much, as the rays do that come from an object, which is at ſuch a diſtance from the eye as

to be ſeen diſtinctly, theſe being received by the eye will make on the bottom of the eye a diſtinct repreſentation of the point F. In like manner the rays, which paſs through the object glaſs A B to the point E after proceeding through the eye-glaſs C D will on the bottom of the eye make a diſtinct repreſentation of the point E. But if the eye be placed where theſe rays, which proceed from E, croſs thoſe, which proceed from F, the eye will receive the diſtinct impreſſion of both theſe points at the ſame time; and conſequently will alſo receive a diſtinct impreſſion from all the intermediate parts of the image E F, that is, the eye will ſee the object, to which the teleſcope is directed, diſtinctly. The place of the eye is about the point G, where the rays H E, H F croſs, which paſs through the middle of the object-glaſs A B to the points E and F; or at the place where the focus would be formed by rays coming from the point H, and refracted by the glaſs C D. To judge how much this inſtrument magnifies any object, we muſt firſt obſerve, that the angle under E H F, in which the eye at the point H would ſee the image E F, is nearly the ſame as the angle, under which the object appears by direct viſion; but when the eye is in G, and views the object through the teleſcope, it ſees the ſame under a greater angle; for the rays, which coming from E and F croſs in G, make a greater angle than the rays, which proceed from the point H to theſe points E and F. The angle at G is greater than that at H in the proportion, as the diſtance between the glaſſes A B and C D is greater than the diſtance of the point G from the glaſs C D.

16. This teleſcope inverts the object; for the rays, which come from the right-hand ſide of the object, go to the point E the left ſide of the image; and the rays, which come from the left ſide of the object, go to F the right ſide of the image. Theſe rays croſs again in G, ſo that the rays, which come from the right ſide of the object, go to the right ſide of the eye; and the rays from the left ſide of the object go to the left ſide of the eye. Therefore in this teleſcope the image in the eye has the ſame ſituation as the object; and ſeeing that in direct viſion the image in the eye has an inverted ſituation, here, where the ſituation is not inverted, the object muſt appear ſo. This is no inconvenience to aſtronomers in celeſtial obſervations; but for objects here on the earth it is uſual to add two other convex glaſſes, which may turn the object again (as is repreſented in fig. 157,) or elſe to uſe the other kind of teleſcope with a concave eye-glaſs.

17. In this other kind of teleſcope the effect is founded on the ſame principles, as in the former. The diſtinctneſs of the appearance is procured in the ſame manner. But here the eye-glaſs C D (in fig. 156) is placed between the image E F, and the object glaſs A B. By this means the rays, which come from the right-hand ſide of the object, and proceed toward E the left ſide of the image, being intercepted by the eye-glaſs are carried to the left ſide of the eye; and the rays, which come from the left ſide of the object, go to the right ſide of the eye; ſo that the impreſſion in the eye being inverted the object appears in the ſame ſituation,

as when view'd by the naked eye. The eye muſt here be placed cloſe to the glaſs. The degree of magnifying in this inſtrument is thus to be found. Let the rays, which paſs through the glaſs A B at H, after the refraction of the eye-glaſs C D diverge, as if they came from the point G; then the rays, which come from the extremities of the object, enter the eye under the angle at G; ſo that here ~~alſo the~~ object will be magnified in the proportion of the diſtance between the glaſſes, to the diſtance of G from the eye-glaſs.

18. The ſpace, that can be taken in at one view in this teleſcope, depends on the breadth of the pupil of the eye; for as the rays, which go to the points E, F of the image, are ſomething diſtant from each other, when they come out of the glaſs C D, if they are wider aſunder than the pupil, it is evident, that they cannot both enter the eye at once. In the other teleſcope the eye is placed in the point G, where the rays that come from the points E or F croſs each other, and therefore muſt enter the eye together. On this account the teleſcope with convex glaſſes takes in a larger view, than thoſe with concave. But in theſe alſo the extent of the view is limited, becauſe the eye-glaſs does not by the refraction towards its edges form ſo diſtinct a repreſentation of the object, as near the middle.

18. Microſcopes are of two ſorts. One kind is only a very convex glaſs, by the means of which the object may be brought very near the eye, and yet be ſeen diſtinctly.

This microſcope magnifies in proportion, as the object by being brought near the eye will form a broader impreſſion on the optic nerve. The other kind made with convex glaſſes produces its effects in the ſame manner as the teleſcope. Let the object A B (in fig. 158) be placed under the glaſs C D, and by this glaſs let an image be formed of this object. Above this image let the glaſs G H be placed. By this glaſs let the rays, which proceed from the points A and B, be refracted, as is expreſſed in the figure. In particular, let the rays, which from each of theſe points paſs through the middle of the glaſs C D, croſs in I, and there let the eye be placed. Here the object will appear larger, when ſeen through the microſcope, than if that inſtrument were removed, in proportion as the angle, in which theſe rays croſs in I, is greater than the angle, which the lines would make, that ſhould be drawn from I to A and B; that is, in the proportion made up of the proportion of the diſtance of the object A B from I, to the diſtance of I from the glaſs G H; and of the proportion of the diſtance between the glaſſes, to the diſtance of the object A B from the glaſs C D.

19. I SHALL now proceed to explain the imperfection in theſe inſtruments, occaſioned by the different refrangibility of the light which comes from every object. This prevents the image of the object from being formed in the focus of the object glaſs with perfect diſtinctneſs; ſo that if the eye-glaſs magnify the image overmuch, the imperfections of it muſt be viſible, and make the whole appear confuſed. Our author more fully to ſatisfy himſelf, that the different refrangibility of the

ſeveral ſorts of rays is ſufficient to produce this irregularity, underwent the labour of a very nice and difficult experiment, whoſe proceſs he has at large ſet down, to prove, that the rays of light are refracted as differently in the ſmall refraction of teleſcope glaſſes as in the larger of the priſm; ſo exceeding careful has he been in ſearching out the true cauſe of this effect. And he uſed, I ſuppoſe, the greater caution, becauſe another reaſon had before been generally aſſigned for it. It was the opinion of all mathematicians, that this defect in teleſcopes aroſe from the figure, in which the glaſſes were formed; a ſpherical refracting ſurface not collecting into an exact point all the rays which come from any one point of an object, as has before been ſaid [a]. But after our author has proved, that in theſe ſmall refractions, as well as in greater, the ſine of incidence into air out of glaſs, to the ſine of refraction in the red-making rays, is as 50 to 77, and in the blue-making rays 50 to 78; he proceeds to compare the inequalities of refraction ariſing from this different refrangibility of the rays, with the inequalities, which would follow from the figure of the glaſs, were light uniformly refracted. For this purpoſe he obſerves, that if rays iſſuing from a point ſo remote from the object glaſs of a teleſcope, as to be eſteemed parallel, which is the caſe of the rays, which come from the heavenly bodies; then the diſtance from the glaſs of the point, in which the leaſt refrangible rays are united, will be to the diſtance, at which the moſt refrangible rays unite, as 28 to 27; and therefore that the leaſt ſpace, into which all the rays can be collected, will not be leſs than the 55th part of the breadth of the the glaſs. For if A B (in fig. 159) be the glaſs, C D its axis, E A, F B two rays of the light parallel to that axis entring the glaſs near its edges; after refraction let the leaſt refrangible part of theſe rays meet in G, the moſt refrangible in H; then, as has been ſaid, G I will be to I H, as 28 to 27; that is, G H will be the 28th part of G I, and the 27th part of H I; whence if K L be drawn through G, and M N through H, perpendicular to C D, M N will be the 28th part of A B, the breadth of the glaſs, and K L the 27th part of the ſame; ſo that O P the leaſt ſpace, into which the rays are gathered, will be about half the mean between theſe two, that is the 55th part of A B.

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[a] §. 2.

20. THIS is the error ariſing from the different refrangibility of the rays of light, which our author finds vaſtly to exceed the other, conſequent upon the figure of the glaſs. In particular, if the teleſcope glaſs be flat on one ſide, and convex on the other; when the flat ſide is turned towards the object, by a theorem, which he has laid down, the error from the figure comes out above 5000 times leſs than the other. This other inequality is ſo great, that teleſcopes could not perform ſo well as they do, were it not that the light does not equally fill all the ſpace O P, over which it is ſcattered, but is much more denſe toward the middle of that ſpace than at the extremities. And beſides, all the kinds of rays affect not the ſenſe equally ſtrong, the yellow and orange being the ſtrongeſt,

Fig. 149.

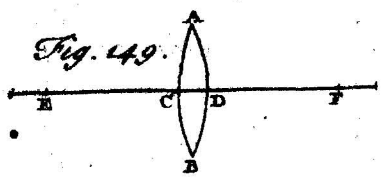
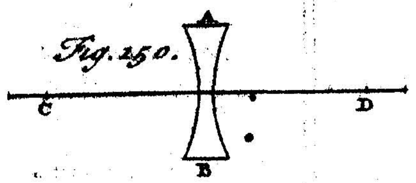


Fig. 150.



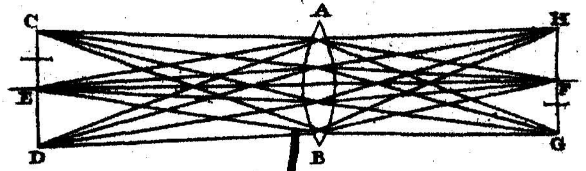
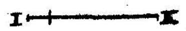


Fig. 151.



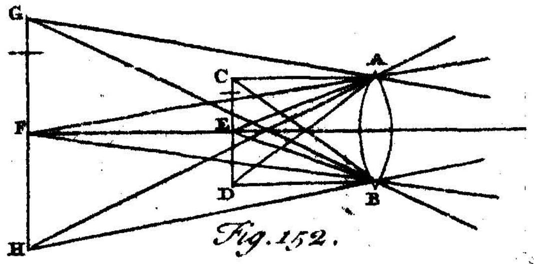


Fig. 152.

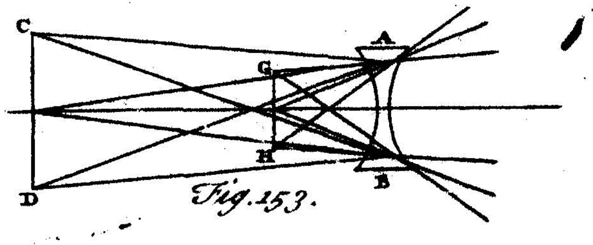


Fig. 153.

Fig. 154.

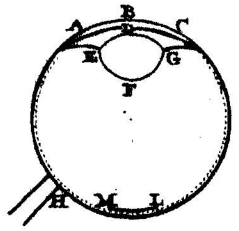


Fig. 155.

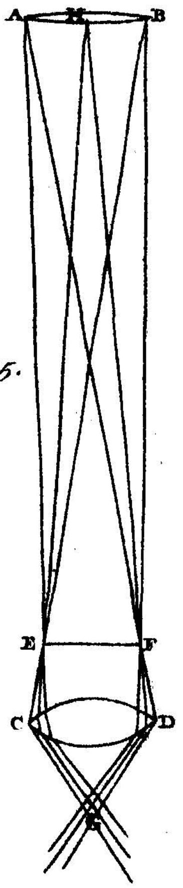


Fig. 156.

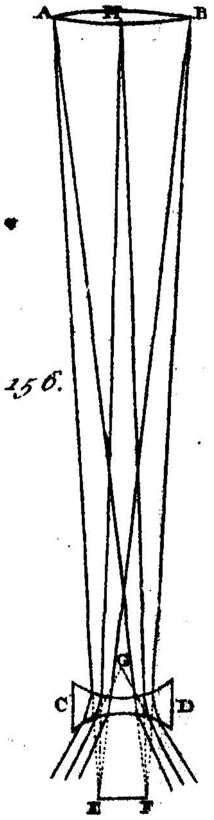
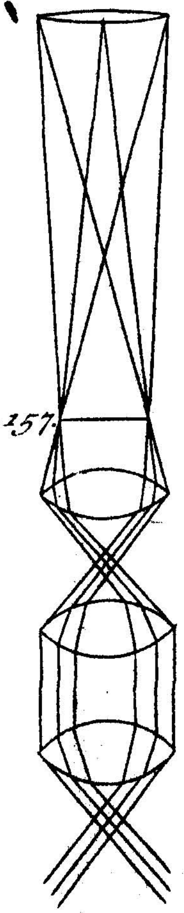


Fig. 157.



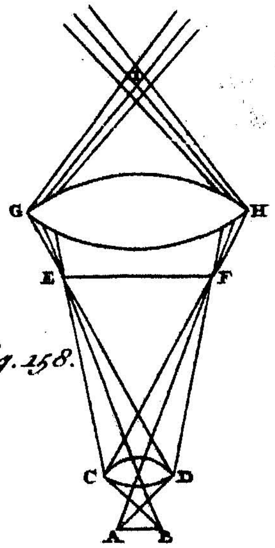
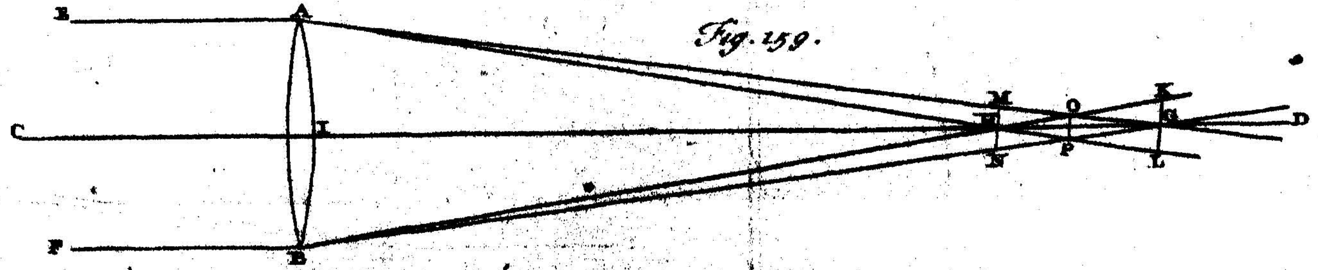


Fig. 158.

Fig. 159.



the red and green next to them, the blue indigo and violet being much darker and fainter colours; and it is ſhewn that all the yellow and orange, and three fifths of the brighter half of the red next the orange, and as great a ſhare of the brighter half of the green next the yellow, will be collected into a ſpace whoſe breadth is not above the 250th part of the breadth of the glaſs. And the remaining colours, which fall without this ſpace, as they are much more dull and obſcure than theſe, ſo will they be likewiſe much more diffuſed; and therefore can hardly affect the ſenſe in compariſon of the other. And agreeable to this is the obſervation of aſtronomers, that teleſcopes between twenty and ſixty feet in length repreſent the fixed ſtars, as being about 5 or 6, at moſt about 8 or 10 ſeconds in diameter. Whereas other arguments ſhew us, that they do not really appear to us of any ſenſible magnitude any otherwiſe than as their light is dilated by refraction. One proof that the fixed ſtars do not appear to us under any ſenſible angle is, that when the moon paſſes over any of them, their light does not, like the planets on the ſame occaſion, diſappear by degrees, but vaniſhes at once.

21. OUR author being thus convinced, that teleſcopes were not capable of being brought to much greater perfection than at preſent by refractions, contrived one by reflection, in which there is no ſeparation made of the different coloured light; for in every kind of light the rays after reflection have the ſame degree of inclination to the ſurface, from whence they are reflected, as they have at their incidence, ſo

that thoſe rays which come to the ſurface in one line, will go off alſo in one line without any parting from one another. Accordingly in the attempt he ſucceeded ſo well, that a ſhort one, not much exceeding ſix inches in length, equalled an ordinary teleſcope whoſe length was four feet. Inſtruments of this kind to greater lengths, have of late been made, which fully anſwer expectation [a].

CHAP. V.

Of the RAINBOW.

I SHALL now explain the rainbow. The manner of its production was underſtood, in the general, before Sir ISAAC NEWTON had diſcovered his theory of colours; but what cauſed the diverſity of colours in it could not then be known, which obliges him to explain this appearance particularly; whom we ſhall imitate as follows. The firſt perſon, who expreſsly ſhewed the rainbow to be formed by the reflection of the ſun-beams from drops of falling rain, was ANTONIO DE DOMINIS. But this was afterwards more fully and diſtinctly explained by DES CARTES.

2. THERE appears moſt frequently two rainbows; both of which are cauſed by the foreſaid reflection of the ſun-beams from the drops of falling rain, but are not produced by all the light which falls upon and are reflected from the drops. The inner bow is produced by thoſe rays only which enter the drop, and at their entrance are ſo refracted as to unite into a point, as it were, upon the farther ſurface of the drop, as is repreſented in fig. 160; where the contiguous rays *a b*, *c d*, *e f*, coming from the

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[a] Philoſ. Tranſ. No. 378.

ſun, and therefore to ſenſe parallel, upon their entrance into the drop in the points *b*, *d*, *f*, are ſo refracted as to meet together in the point *g*, upon the farther ſurface of the drop. Now theſe rays being reflected nearly from the ſame point of the ſurface, the angle of incidence of each ray upon the point *g* being equal to the angle of reflection, the rays will return in the lines *g h*, *g k*, *g l*, in the ſame manner inclined to each other, as they were before their incidence upon the point *g*, and will make the ſame angles with the ſurface of the drop at the points *h*, *k*, *l*, as at the points *b*, *d*, *f*, after their entrance; and therefore after their emergence out of the drop each ray will be inclined to the ſurface in the ſame angle, as when it firſt entered it; whence the lines *h m*, *k n*, *l o*, in which the rays emerge, muſt be parallel to each other, as well as the lines *a b*, *c d*, *e f*, in which they were incident. But theſe emerging rays being parallel will not ſpread nor diverge from each other in their paſſage from the drop, and therefore will enter the eye conveniently ſituated in ſufficient plenty to cauſe a ſenſation. Whereas all the other rays, whether thoſe nearer the center of the drop, as *p q*, *r s*, or thoſe farther off, as *t u*, *w x*, will be reflected from other points in the hinder ſurface of the drop; namely, the ray *p q* from the point *y*, *r s* from *z*, *t v* from *α*, and *w x* from *β*. And for this reaſon by their reflection and ſucceeding refraction they will be ſcattered after their emergence from the forementioned rays and from each other, and therefore cannot enter the eye placed to receive them copious enough to excite any diſtinct ſenſation.

3. The external rainbow is formed by two reflections made between the incidence and emergence of the rays; for it is to be noted, that the rays *g h*, *g k*, *g l*, at the points *h*, *k*, *l*, do not wholly paſs out of the drop, but are in part reflected back; though the ſecond reflection of theſe particular rays does not form the outer bow. For this bow is made by thoſe rays, which after their entrance into the drop are by the refraction of it united, before they arrive at the farther ſurface, at ſuch a diſtance from it, that when they fall upon that ſurface, they may be reflected in parallel lines, as is repreſented in fig. 161; where the rays *a b*, *c d*, *e f*, are collected by the refraction of the drop into the point *g*, and paſſing on from thence ſtrike upon the ſurface of the drop in the points *h*, *k*, *l*, and are thence reflected to *m*, *n*, *o*, paſſing from *h* to *m*, from *k* to *n*, and from *l* to *o* in parallel lines. For theſe rays after reflection at *m*, *n*, *o* will meet again in the point *p*, at the ſame diſtance from theſe points of reflection *m*, *n*, *o*, as the point *g* is from the former points of reflection *h*, *k*, *l*. Therefore theſe rays in paſſing from *p* to the ſurface of the drop will fall upon that ſurface in the points *q*, *r*, *s* in the ſame angles, as theſe rays made with the ſurface in *b*, *d*, *f*, after refraction. Conſequently, when theſe rays emerge out of the drop into the air, each ray will make with the ſurface of the drop the ſame angle, as it made at its firſt incidence; ſo that the lines *q t*, *r v*, *s w*, in which they come from the drop, will be parallel to each other, as well as the lines *a b*, *c d*, *e f*, in which they came to the

drop. By this means theſe rays to a ſpectator commodiouſly ſituated will become viſible. But all the other rays, as well thoſe nearer the center of the drop $x\,y$, $z\,\alpha$, as thoſe more remote from it $\beta\,\gamma$, $\delta\,\epsilon$, will be reflected in lines not parallel to the lines $b\,m$, $k\,n$, $l\,o$; namely, the ray $x\,y$, in the line $\zeta\,\eta$, the ray $z\,\alpha$ in the line $\theta\,\kappa$, the ray $\beta\,\gamma$ in the line $\lambda\,\mu$, and the ray $\delta\,\epsilon$ in the line $\nu\,\xi$. Whence theſe rays after their next reflection and ſubſequent refraction will be ſcattered from the forementioned rays, and from one another, and by that means become inviſible.

4. IT is farther to be remarked, that if in the firſt caſe the incident rays $a\,b$, $c\,d$, $e\,f$, and their correſpondent emergent rays $b\,m$, $k\,n$, $l\,o$, are produced till they meet, they will make with each other a greater angle, than any other incident ray will make with its correſponding emergent ray. And in the latter caſe, on the contrary, the emergent rays $q\,t$, $r\,v$, $s\,w$ make with the incident rays an acuter angle, than is made by any other of the emergent rays.

5. OUR author delivers a method of finding each of theſe extream angles from the degree of refraction being given; by which method it appears, that the firſt of theſe angles is the leſs, and the latter the greater, by how much the refractive power of the drop, or the refrangibility of the rays is greater. And this laſt conſideration fully compleats the doctrine of the rainbow, and ſhews, why the colours of each bow are ranged in the order wherein they are ſeen.

6. Suppose A (in fig. 162.) to be the eye, B, C, D, E, F, drops of rain, Mn, Op, Qr, St, Vw parcels of rays of the ſun, which entring the drops B, C, D, E, F after one reflection paſs out to the eye in A. Now let Mn be produced to η till it meets with the emergent ray likewiſe produced, let Op produced meet its emergent ray produced in κ, let Qr meet its emergent ray in λ, let St meet its emergent ray in μ, and let Vw meet its emergent ray produced in ν. If the angle under $M\eta A$ be that, which is derived from the refraction of the violet-making rays by the method we have here ſpoken of, it follows that the violet light will only enter the eye from the drop B, all the other coloured rays paſſing below it, that is, all thoſe rays which are not ſcattered, but go out parallel ſo as to cauſe a ſenſation. For the angle, which theſe parallel emergent rays makes with the incident in the moſt refrangible or violet-making rays, being leſs than this angle in any other ſort of rays, none of the rays which emerge parallel, except the violet-making, will enter the eye under the angle $M\eta A$, but the reſt making with the incident ray $M\eta$ a greater angle than this will paſs below the eye. In like manner if the angle under $O\kappa A$ agrees to the blue-making rays, the blue rays only ſhall enter the eye from the drop C, and all the other coloured rays will paſs by the eye, the violet-coloured rays paſſing above, the other colours below. Farther, the angle $Q\lambda A$ correſponding to the green-making rays, thoſe only ſhall enter the eye from the drop D, the violet and blue-making rays paſſing above, and the other colours, that is the yellow and

red, below. And if the angle $S\mu A$ anſwers to the refraction of the yellow-making rays, they only ſhall come to the eye from the drop E. And in the laſt place, if the angle $V\nu A$ belongs to the red-making and leaſt refrangible rays, they only ſhall enter the eye from the drop F, all the other coloured rays paſſing above.

7. BUT now it is evident, that all the drops of water found in any of the lines $A\kappa$, $A\lambda$, $A\mu$, $A\nu$, whether farther from the eye, or nearer than the drops B, C, D, E, F, will give the ſame colours as theſe do, all the drops upon each line giving the ſame colour; ſo that the light reflected from a number of theſe drops will become copious enough to be viſible; whereas the reflection from one minute drop alone could not be perceived. But beſides, it is farther manifeſt, that if the line $A\xi$ be drawn from the ſun through the eye, that is, parallel to the lines Mn, Op, Qr, St, Vw, and if drops of water are placed all round this line, the ſame colour will be exhibited by all the drops at the ſame diſtance from this line. Hence it follows, that when the ſun is moderately elevated above the horizon, if it rains oppoſite to it, and the ſun ſhines upon the drops as they fall, a ſpectator with his back turned to the ſun muſt obſerve a coloured circular arch reaching to the horizon, being red without, next to that yellow, then green, blue, and on the inner edge violet; only this laſt colour appears faint by being diluted with the white light of the clouds, and from another cauſe to be mentioned hereafter[*].

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[*] § 11.

8. THUS is cauſed the interior or primary bow. The drops of rain at ſome diſtance without this bow will cauſe the exterior or ſecondary bow by two reflections of the ſun's light. Let theſe drops be G, H, I, K, L; Χγ, Ζα, Γβ, Δδ, Θζ denoting parcels of rays which enter each drop. Now it has been remarked, that theſe rays make with the viſible refracted rays the greateſt angle in thoſe rays, which are moſt refrangible. Suppoſe therefore the viſible refracted rays, which paſs out from each drop after two reflections, and enter the eye in A, to interſect the incident rays in π, ρ, σ, τ, φ reſpectively. It is manifeſt, that the angle under ΘφA is the greateſt of all, next to that the angle under ΔτA, the next in bigneſs will be the angle under ΓσA, the next to this the angle under ΖρA, and the leaſt of all the angle under ΧπA. From the drop L therefore will come to the eye the violet-making, or moſt refrangible rays, from K the blue, from I the green, from H the yellow, and from G the red-making rays; and the like will happen to all the drops in the lines Aπ, Aρ, Aτ, Aφ, and alſo to all the drops at the ſame diſtances from the line AZ all round that line. Whence appears the reaſon of the ſecondary bow, which is ſeen without the other, having its colours in a contrary order, violet without and red within; though the colours are fainter than in the other bow, as being made by two reflections, and two refractions; whereas the other bow is made by two refractions, and one reflection only.

9. THERE is a farther appearance in the rainbow particularly deſcribed about five years ago[a], which is, that under the upper part of the inner bow there appears often two or three orders of very faint colours, making alternate arches of green, and a reddiſh purple. At the time this appearance was taken notice of, I gave my thoughts concerning the cauſe of it[b], which I ſhall here repeat. Sir ISAAC NEWTON has obſerved, that in glaſs, which is poliſhed and quickſilvered, there is an irregular refraction made, whereby ſome ſmall quantity of light is ſcattered from the principal reflected beam[c]. If we allow the ſame thing to happen in the reflection whereby the rainbow is cauſed, it ſeems ſufficient to produce the appearance now mentioned.

10. LET AB (in fig. 162.) repreſent a globule of water, B the point from whence the rays of any determinate ſpecies being reflected to C, and afterwards emerging in the line CD, would proceed to the eye, and cauſe the appearance of that colour in the rainbow, which appertains to this ſpecies. Here ſuppoſe, that beſides what is reflected regularly, ſome ſmall part of the light is irregularly ſcattered every way; ſo that from the point B, beſides the rays that are regularly reflected from B to C, ſome ſcattered rays will return in other lines, as in BE, BF, BG, BH, on each ſide the line BC. Now it has been obſerved above[d], that the rays of light in their paſſage from one ſuperficies of a refracting body to the other undergo alternate fits of

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[a] Philoſ. Tranſact. No. 375.

[b] Ibid.

[c] Opt. B. II. part 4.

[d] Ch. 3. § 14.

eaſy tranſmiſſion and reflection, ſucceeding each other at equal intervals; inſomuch that if they reach the farther ſuperficies in one ſort of thoſe fits, they ſhall be tranſmitted; if in the other kind of them, they ſhall rather be reflected back. Whence the rays that proceed from B to C, and emerge in the line CD, being in a fit of eaſy tranſmiſſion, the ſcattered rays, that fall at a ſmall diſtance without theſe on either ſide (ſuppoſe the rays that paſs in the lines BE, BG) ſhall fall on the ſurface in a fit of eaſy reflection, and ſhall not emerge; but the ſcattered rays, that paſs at ſome diſtance without theſe laſt, ſhall arrive at the ſurface of the globule in a fit of eaſy tranſmiſſion, and break through that ſurface. Suppoſe theſe rays to paſs in the lines BF, BH; the former of which rays ſhall have had one fit more of eaſy tranſmiſſion, and the latter one fit leſs, than the rays that paſs from B to C. Now both theſe rays, when they go out of the globule, will proceed by the refraction of the water in the lines FI, HK, that will be inclined almoſt equally to the rays incident on the globule, which come from the ſun; but the angles of their inclination will be leſs than the angle, in which the rays emerging in the line CD are inclined to thoſe incident rays. And after the ſame manner rays ſcattered from the point B at a certain diſtance without theſe will emerge out of the globule, while the intermediate rays are intercepted; and theſe emergent rays will be inclined to the rays incident on the globule in angles ſtill leſs than the angles, in which the rays FI and HK are inclined to them; and without theſe rays will emerge other rays, that ſhall be inclined to the incident rays in angles yet leſs. Now

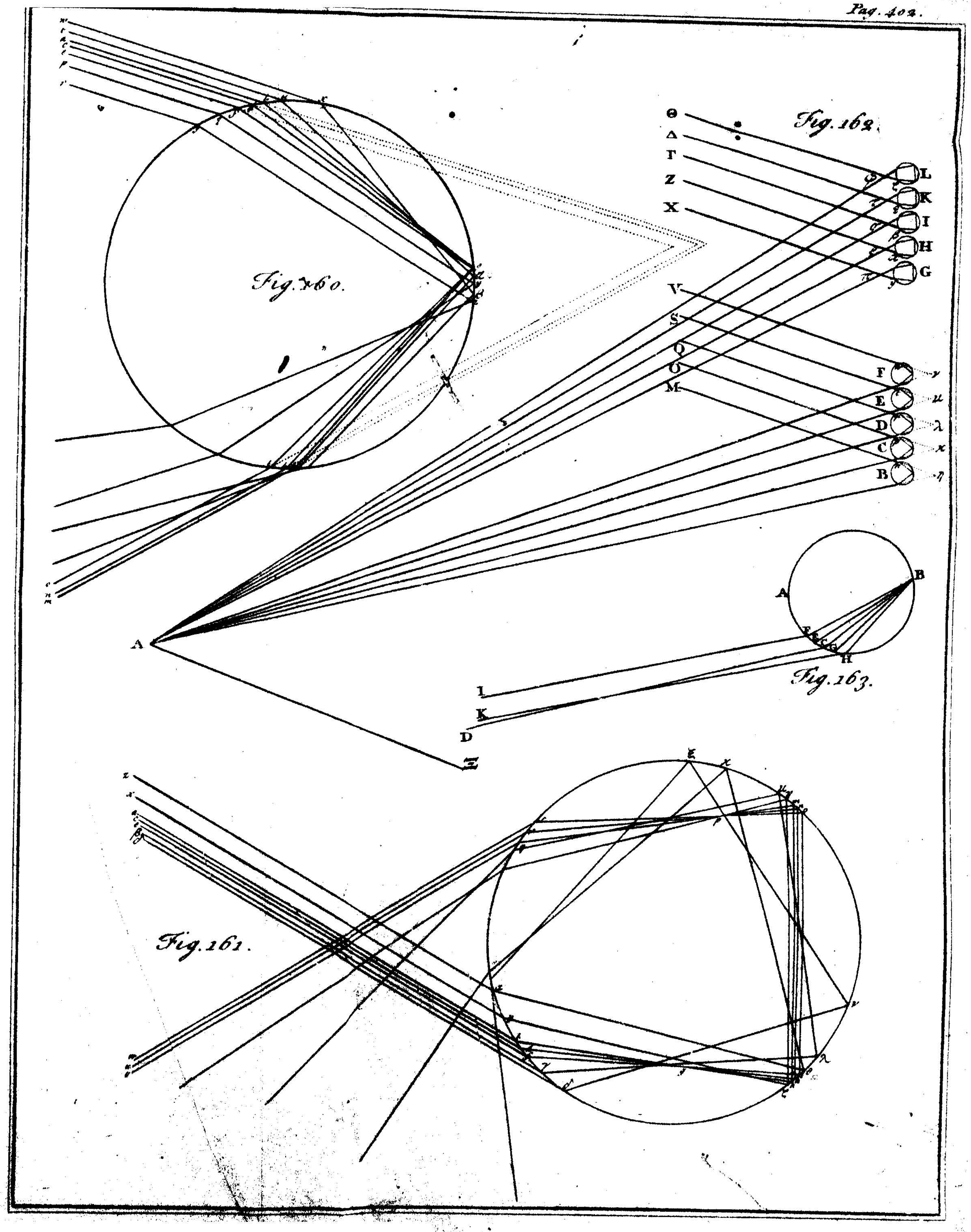

Fig. 160.

Fig. 161.

Fig. 162.

Fig. 163.

by this means may be formed of every kind of rays, beſides the principal arch, which goes to the formation of the rainbow, other arches within every one of the principal of the ſame colour, though much more faint; and this for divers ſucceſſions, as long as theſe weak lights, which in every arch grow more and more obſcure, ſhall continue viſible. Now as the arches produced by each colour will be variouſly mixed together, the diverſity of colours obſerv'd in theſe ſecondary arches may very poſſibly ariſe from them.

11. IN the darker colours theſe arches may reach below the bow, and be ſeen diſtinct. In the brighter colours theſe arches are loſt in the inferior part of the principal light of the rainbow; but in all probability they contribute to the red tincture, which the purple of the rainbow uſually has, and is moſt remarkable when theſe ſecondary colours appear ſtrongeſt. However theſe ſecondary arches in the brighteſt colours may poſſibly extend with a very faint light below the bow, and tinge the purple of theſe ſecondary arches with a reddiſh hue.

12. THE preciſe diſtances between the principal arch and theſe fainter arches depend on the magnitude of the drops, wherein they are formed. To make them any degree ſeparate it is neceſſary the drop be exceeding ſmall. It is moſt likely, that they are formed in the vapour of the cloud, which the air being put in motion by the fall of the rain may carry down along with the larger drops; and this may be the reaſon, why theſe colours appear under the upper

part of the bow only, this vapour not deſcending very low. As a farther confirmation of this, theſe colours are ſeen ſtrongeſt, when the rain falls from very black clouds, which cauſe the fierceſt rains, by the fall whereof the air will be moſt agitated.

13. TO the like alternate return of the fits of eaſy tranſmiſſion and reflection in the paſſage of light through the globules of water, which compoſe the clouds, Sir ISAAC NEWTON aſcribes ſome of thoſe coloured circles, which at times appear about the ſun and moon[a].

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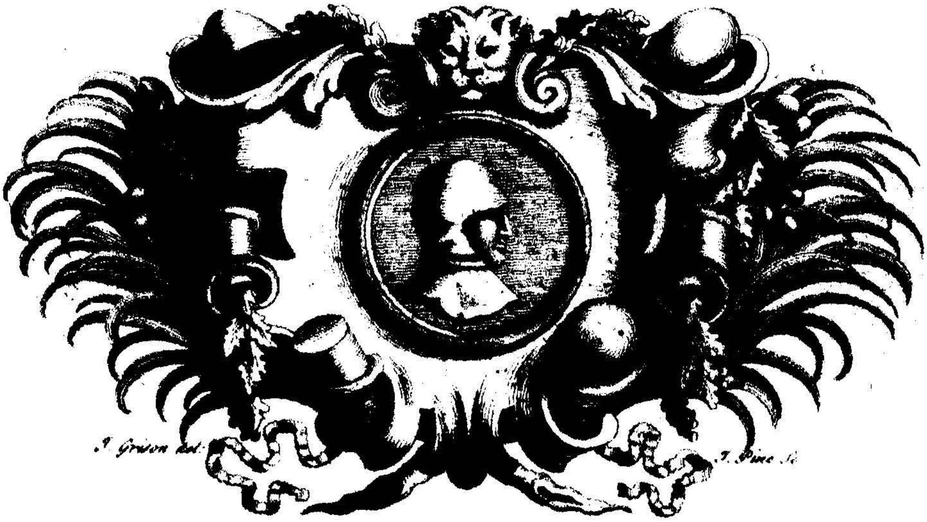
[a] Opt. B. II. part 4. obſ. 13.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CONCLUSION.

SIR ISAAC NEWTON having concluded each of his philoſophical treatiſes with ſome general reflections, I ſhall now take leave of my readers with a ſhort account of what he has there delivered. At the end of his mathematical principles of natural philoſophy he has given us his thoughts concerning the Deity. Wherein he firſt obſerves, that the ſimilitude found in all parts of the univerſe makes it undoubted, that the whole is governed by one ſupreme being, to whom the original is owing of the frame of nature, which evidently is the effect of choice and deſign. He then proceeds briefly to ſtate the beſt metaphyſical notions concerning God. In ſhort, we cannot conceive either of ſpace or time otherwiſe than as neceſſarily exiſting; this Being therefore, on whom all others depend, muſt certainly exiſt by the ſame neceſſity of nature. Conſequently wherever ſpace and time is found, there God muſt alſo be. And as it appears impoſſible to us, that ſpace ſhould be limited, or that time ſhould have had a beginning, the Deity muſt be both immenſe and eternal.

2. At the end of his treatiſe of optics he has propoſed ſome thoughts concerning other parts of nature, which he had not diſtinctly ſearched into. He begins with ſome farther reflections concerning light, which he had not fully examined. In particular he declares his ſentiments at large concerning the power, whereby bodies and light act on each other. In ſome parts of his book he had given ſhort hints at his opinion concerning this [a], but here he expreſsly declares his conjecture, which we have already mentioned [b], that this power is lodged in a very ſubtle ſpirit of a great elaſtic force diffuſed thro' the univerſe, producing not only this, but many other natural operations. He thinks it not impoſſible, that the power of gravity itſelf ſhould be owing to it. On this occaſion he enumerates many natural appearances, the chief of which are produced by chymical experiments. From numerous obſervations of this kind he makes no doubt, that the ſmalleſt parts of matter, when near contact, act ſtrongly on each other, ſometimes being mutually attracted, at other times repelled.

3. The attractive power is more manifeſt than the other, for the parts of all bodies adhere by this principle. And the

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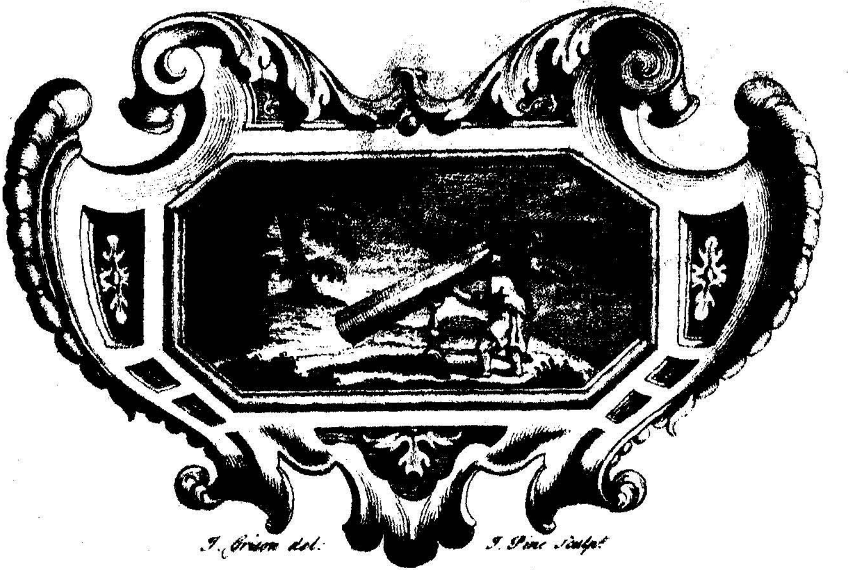
[a] Opt. pag. 255.

[b] Ch. 3. § 18.

name of attraction, which our author has given to it, has been very freely made uſe of by many writers, and as much objected to by others. He has often complained to me of having been miſunderſtood in this matter. What he ſays upon this head was not intended by him as a philoſophical explanation of any appearances, but only to point out a power in nature not hitherto diſtinctly obſerved, the cauſe of which, and the manner of its acting, he thought was worthy of a diligent enquiry. To acquieſce in the explanation of any appearance by aſſerting it to be a general power of attraction, is not to improve our knowledge in philoſophy, but rather to put a ſtop to our farther ſearch.

FINIS.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کتاب کالج فورٹ ولیم
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